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Analytical methods for estimating nutritive value of crop residues

Screening stylo accessions for anthracnose

Sequential cropping on Ethiopian Vertisols

The *ILCA Bulletin* is a quarterly publication of the International Livestock Centre for Africa. Contributions to the Bulletin are invited from livestock researchers in Africa whose work is related to that of ILCA. The *ILCA Bulletin* is distributed to more than 3000 researchers, policy makers, donors and extension agents throughout sub-Saharan Africa and elsewhere in the world.

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Preface

Historically, animal traction had been a somewhat neglected technology, scornfully considered by some as a 'U-turn to the stone age'. This is no longer so, thanks to the sometimes bitter lessons learnt from over-ambitious tractorisation schemes and the world-wide drive to promote technologies that enable economically and ecologically sustainable increases in agricultural production.

The growing interest in animal traction has been reflected also in papers published in *ILCA Bulletin:* we recently carried articles on how to measure work performance of oxen under field conditions and on feeding regimes for draught oxen in subhumid Nigeria. In this issue, the nutrition of draught oxen is addressed from yet another viewpoint.

In Africa, cereal crop residues, rather than grass, browse or concentrate feeds, constitute the major feed resource for working animals. Knowing the nutritive value of these residues will help farmers formulate feed rations which will enable the animals to maintain strength and even gain weight without becoming fat and lazy. Intake and digestibility, the two determinants of the nutritive value of any feed, can be estimated by a number of analytical methods. The advantages and disadvantages of five such methods are discussed in the first paper of this *Bulletin* issue, in the context of their possible use by African research institutions.

As in the case of animal traction, the interest in forage legumes to improve the stability of tropical grasslands, and animal production from them, has intensified during the past two decades. This is particularly true about *Stylosanthes* cultivars, which are among the most widely distributed pasture plants in the tropics and subtropics.

No longer relying on 'pick-the-winner' philosophy, pasture development programmes in these regions aim at developing productive cultivars with good persistence on overgrazed and eroded land and lower susceptibility to anthracnose, a fungal disease which is believed to have come to Africa from South America, the centre of origin of many *Stylosanthes* species. Screening for anthracnose tolerance has been an integral part of ILCA's forage legume research in subhumid Nigeria. The results of this screening are presented in this issue.

Draught animals hitched to a mouldboard plough, a harrow or a ridger are often used to plow virgin or fallow land and to prepare the seedbed. In the Ethiopian highlands, where waterlogging of Vertisols (black cracking clays) prevents cropping during the greater part of the growing season, they can also be used to shape the land into broadbeds and furrows, which help conserve excess water for cropping after the rainy season. Trials at a midaltitude research site showed that sequential cropping is possible if the germination of the second crop is assisted by irrigation at planting with water supplied through the drainage furrows from a head ditch.

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Estimating the nutritive value of cereal crop residues: Implications for developing feeding standards for draught animals

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SUMMARY

ANALYTICAL METHODS *for the determination of the nutritive value of cereal crop residues are reviewed, the emphasis being given to methods used to estimate total plant cell wall and its digestibility. Examples are given of the accuracy of different methods in determining digestibility and of the factors affecting it. Various management practices for feeding cereal crop residues to draught animals are highlighted.*

INTRODUCTION

Approximately 15% of the arable land in sub-Saharan Africa is cultivated by smallholders using animal traction (ILCA, 1981). Obtaining adequate feed for draught animals is one of the main problems these farmers face, especially at the end of the dry season before cultivation starts.

Cereal crop residues constitute a major feed resource for working animals in most African countries; grassland vegetation, stored hay and fibrous byproducts, such as pulses, oil plants, sugarcane, roots and tubers, are less important. Few smallholders have easy access to, or can afford, concentrate feeds. The quantity and quality of crop residues available, and the farmers' feeding strategies, thus have a direct effect on the nutrition of draught animals.

In 1981, an estimated 236 million tonnes of cereal crop residues were produced in Africa. Nearly 70% of the residues were derived from cereals, with maize, millet and sorghum providing the largest portion in sub-Saharan Africa. Throughout the continent, the amount of crop residues produced averaged 1.5 t of feed per livestock unit per year (Kossila, 1984).

In West Africa, draught animals (cattle, donkeys and horses) commonly receive diets composed of maize, millet and sorghum stover, rice straw, groundnut and bean haulms, and maize and millet cobs. These residues may be fed separately or as a mixture, and sometimes they may be supplemented with cowpea or groundnut hay or with agro-industrial byproducts, such as cottonseed and groundnut cake or brewer's grains.

Farmers in the Ethiopian highlands have a tradition of conserving crop residues from teff *(Eragrostis tef),* barley, wheat and sorghum. In Kenya, oxen are fed stored maize stover, and pigeon pea and cowpea residues (Tessema, 1984). Maize, millet and sorghum stover are the main crop residues available for working animals and other livestock in Botswana and

Tanzania (Mayer, 1983; Urio, 1985). In Lesotho, Malawi, Zambia and Zimbabwe, maize stover and other cereal crop residues provide the bulk of the diet fed to draught animals (Chabala, 1984; Molapo et al, 1984; Shumba, 1984; Watson et al, 1984).

Many researchers in Africa and elsewhere (including Reh, 1982; Goe, 1983, 1987; Upadhyay et al, 1983; Mathers, 1984; Mathers et al, 1985; Bamualim and Kartiarso, 1985; Ibrahim, 1985; Lawrence, 1985; Wanapat, 1985; Abiye Astatke et al, 1986; Pearson, 1986; Soller et al, 1986) have shown interest in determining energy requirements of, and/or developing feeding standards for, working animals, particularly cattle.

A comparison of five analytical systems in terms of their advantages and disadvantages is given in this paper. For a detailed description of the techniques reviewed, the reader is referred to cited literature. It should be noted that while the discussion in this paper focuses on draught cattle, the analytical methods and the crop residue management practices highlighted are relevant to other livestock, e.g., sheep and goats, as well.

NUTRITIVE VALUE OF CEREAL CROP RESIDUES

Cereal crop residues are deficient in nitrogen and have a high cell-wall content. Both factors reduce their intake and digestibility. Supplementation with non-protein nitrogen or high-protein feedstuffs may improve intake and digestibility, but cannot always compensate for other anti-nutritional factors, such as high fibre content and presence of phenolic compounds (Donefer et al, 1969; Ørskov and Grubb, 1978; Chesson and Ørskov, 1984). It is necessary to study the factors that limit energy intake from cereal crop residues, because large increases in animal productivity can be achieved by relatively small increases in digestibility and intake.

The physical properties of cereal crop residues are to a large extent determined by the characteristics of their cell walls (Van Soest, 1967). Cell wall polysaccharides (cellulose and hemicellulose) account for more than 70% of the dry matter in cereal crop residues and are a major energy source for the microbial production of protein and volatile fatty acids in the rumen.

However, cell-wall content is negatively correlated with intake. High cell-wall content increases rumination time and is associated with decreased efficiency of conversion of metabolisable energy to net energy. The ability of the rumen microorganisms to digest cell-wall polysaccharides is limited by the presence of phenolic and other aromatic compounds (Hartley, 1981).

ANALYTICAL METHODS

Detergent system

No single chemical analysis currently exists which is able to describe the biodegradability of cell-wall matter by rumen micro-organisms. Such a description may, however, be possible by combining the results of a sufficient number of analyses (Van Soest, 1982).

The detergent system of analysis, which is described below, was designed to replace the proximate analysis system in estimating the nutritive value of fibrous feeds. The major problem of the proximate analysis system is that it does not separate feeds into meaningful nutritive fractions and results in losses of cellulose, hemicellulose and lignin and other significant

components of fibre (Van Soest, 1967; Van Soest and Robertson, 1980). In comparison, the detergent system is based on the separation of feeds into fractions with uniform or non-uniform nutritive availability, as defined by the Lucas test (Lucas et al, 1961; Van Soest, 1967).

The test for uniform nutritive availability involves an analysis of the digestible amount of a feed fraction regressed on the percentage of the fraction in feed. For feed fractions that are represented in faeces by indigestible amounts of feed, microbial debris and endogenous excretions, the slope represents true digestibility and the negative intercept estimates the endogenous secretions as a percentage of intake. A feed fraction with uniform nutritive availability has a regression equation with a low standard error and an intercept less than or equal to zero. A high correlation coefficient is not indicative of uniform nutritive availability.

Cell contents and protein are feed fractions which usually have uniform nutritive availability. Both these feed fractions have true digestibility greater than 90% and negative intercepts. Lignin is a nutritionally uniform feed fraction with a true digestibility not significantly different from zero.

Cell wall, cellulose and hemicellulose are feed fractions with non-uniform nutritive availability. They have regression equations with high standard errors. Negative intercepts in this case have no biological meaning because there can be no endogenous excretion of cell-wall carbohydrates.

Neutral-detergent fibre

The separation into uniform and non-uniform feed fractions is achieved by neutral-detergent extraction. The technique separates cell contents (uniform) from the cell wall (non-uniform) in feeds, and bacterial and endogenous debris from undigested cell wall in faeces (Mason, 1979). Neutral-detergent fibre (NDF) consists of cellulose, hemicellulose and lignin, which are major cell-wall fractions. Biogenic silica and pectins are not recovered in NDF, but soil silica, heat-damaged proteins and tannin-protein complexes are.

Acid-detergent fibre

Acid-detergent fibre (ADF) is a preparatory extraction for the determination of cellulose, lignin, total silica and heat-damaged protein (Van Soest and Wine, 1967).

An estimate of heat-damaged protein (Maillard products) is made by a determination of nitrogen in the ADF, using the Kjeldahl method. The Maillard reaction is a polymerisation of proteins with carbohydrates (mainly pentoses in hemicellulose) caused by heating due to industrial processes or fermentation.

Heat-damaged proteins are indigestible. Oilseed meals usually have low ADF nitrogen when oils are extracted by press or solvent without heating. But other byproducts, such as brewer's grains, tomato pomace and byproducts from the extraction of essential oils, can have high ADF nitrogen (Wohet et al, 1981).

Oven drying at temperatures above 60°C to enable feed analysis can result in heat-damaged protein and increased fibre and lignin values. Lignin is a phenolic polymer which lowers the digestibility of cell-wall carbohydrates. Acid-detergent extraction removes all proteins except those that are closely associated with lignin or are damaged by heat. Treatment of ADF with 72% sulphuric acid removes cellulose. The organic residue is mostly lignin unless the feed

contains heat-damaged protein or cutin. Sequential treatment of ADF with potassium permanganate and 72°/o sulphuric acid leaves an organic residue of cutin.

Silica is recovered in ADF ash treated with hydrobromic acid to remove other acid-insoluble minerals. Biogenic silica lowers dry-matter digestibility between 1.4 and 3.0 units for each unit of silica, either by inhibiting cell-wall digestion or by acting as a diluent (Van Soest, 1982). Soil silica, which is also recovered in ADF ash, has no effect on digestibility of other feed components.

Attempts to use ADF as a replacement for crude fibre in digestibility predictions are erroneous and beset by the same problems as the proximate analysis system. This is because such use of ADF is founded on statistical associations which have very little biological meaning. The intended use of ADF is as a preparative residue, not as a digestibility predictor (Van Soest and Robertson, 1980).

Microfibre apparatus

Research groups in developing countries have been slow to adopt newer methods of forage fibre analysis (such as the neutral-detergent system) because of the high cost of reagents and apparatus. ILCA's Nutrition Unit has developed a microfibre apparatus which costs a fraction of the amount of the conventional fibre apparatus and uses one tenth of the amount of reagent. Also, results demonstrate that the microfibre method is comparable to the conventional NDF method and has the same range of error (± 2 units) (Reed, 1984).

ESTIMATING DIGESTIBILITY

Digestibility ranks next to intake in importance for determining the nutritive value of feedstuffs. There are four general methods which can be used to estimate the digestibility of feed resources:

- Enzyme methods, which use fungal cellulases after pretreatment with proteolytic enzymes or detergents;
- Prediction equations, which are based on chemical analysis of cell wall and lignin;
- In vitro techniques using rumen microbes; and
- Cloth-bag methods.

Enzyme systems

Laboratory methods which rely on incubation with commercially available enzymes (fungal cellulases) to estimate digestibility of cereal crop residues and forages are inadequate to develop relevant feeding recommendations for draught animals in the tropics. The major disadvantages associated with such systems are the variable quality of commercially produced enzymes, inability of the enzyme to adapt to a substrate, completeness[1] of the enzyme component and poor cell-wall digestibility (McQueen and Van Soest, 1975; Dowman and Collins, 1977; Van Soest, 1982).

[1]Purified cellulase preparations are less effective in digesting cell-wall carbohydrates than less purified enzyme preparations which have enzymes that digest carbohydrates and other cellulose and may also digest protein.

Cellulase methods underestimate the digestibility of fibrous feeds, so such values must be corrected by regression equations using in vivo values. However, there is a large variation in regression coefficients obtained by different research groups, probably due to the type of feed analysed and the method employed. This large variation in coefficients indicates an inconsistent biological relationship between in vivo digestion and degradability by cellulase.

The limited reliability of cellulase methods to predict accurately the nutritive value of cereal crop residues was demonstrated in an ILCA study (ILCA, 1985). Two cellulase methods were used to determine fibre digestibility in 27 straw samples taken from farms in the Ethiopian highlands keeping draught animals. These were:

- Method 1: Pretreatment with pepsin/ hydrochloric acid (HCI) for 48 hours followed by incubation with cellulase for 48 hours (Goto and Minson, 1977); and
- Method 2: Incubation of the neutral-detergent fibre fraction of the forage with cellulase for 48 hours (Hartley et al, 1974).

Fibre digestibilities by these two methods were compared with fibre digestibilities obtained for the same samples by the action of rumen micro-organisms in vitro (Goering and Van Soest, 1970). The mean in vitro fibre digestibility was 36.9 and 22.3 units greater than the estimates from Method 1 and Method 2, respectively. Cellulase methods are thus less effective than rumen micro-organisms in digesting fibre from cereal crop residues. Nefzaoui and Vanbelle (1985), who reviewed much of the literature comparing the accuracy of enzyme methods with in vitro techniques, arrived at a similar conclusion.

Summative equation

The summative equation is based on the logic of the Lucas test for uniform nutritive availability. Unlignified cellular contents have an assumed mean true digestibility of 98%. Cell-wall digestibility is estimated by regression on the lignin content of ADF (Goering and Van Soest, 1970; Van Soest, 1982). The sum of the digestible cell wall and digestible cell contents is then an estimate of true digestibility.

Apparent digestibility is obtained by subtracting an estimate of metabolic faecal loss from true digestibility. A correction for the effects of silica on digestibility is applied when opaline biogenic silica is greater than 2%.

In Table 1, the summative equation for 34 samples of straw fed to draught oxen in the Ethiopian highlands gave the same estimate of apparent digestibility as the Tilley and Terry in vitro method (Tilley and Terry, 1963). A metabolic faecal loss amount of 12.9 units and a silica correction factor of 1.4 were used in the summative equation.

Table 1. *Comparison of the summative equation and the Tilley and Terry in vitro method in estimating apparent digestible dry matter of 34 straw samples.*

Apparent digestible dry matter				Paired t-test difference[1]	
Summative equation		Tilley and Terry in vitro			
Mean	SD	Mean	SD	Mean	SD
54.4	2.4	54.3	3.9	0.04	2.8

[1] The difference between means is not significant (P>0.05).
Source: Goe (1987).

Fibre quality as affected by lignin and silica is an important aspect in the use of cereal crop residues. Table 2 shows that NDF usually exceeds 70% of the dry matter, with some variation between species and plant fractions. The lignin content of cereal crop residues is low compared with that of residues from dicotyledons, thus potentially, digestible fibre in cereal crop residues is greater. However, this greater digestibility may not be reached because nitrogen and other microbial nutrients are limiting.

Table 2. *Nitrogen (N), neutral-detergent fibre (NDF), acid-detergent fibre (ADF), lignin (LG), silica (SIL) and apparent digestible dry matter (ADDM) in cereal crop residues fed to livestock in Africa.*

Residues	N	NDF	ADF	LG	SIL	ADDM[1]
	%					
Maize	0.81	75.5	51.3	4.8	5.2	57.2
Maize upper stalk	0.41	75.8	44.8	4.8	2.0	58.6
Maize leaf sheath	0.33	83.9	47.4	4.8	2.2	57.1
Maize tassel	0.79	82.3	46.2	7.9	5.1	38.8
Sorghum leaf sheath	0.25	79.9	53.2	6.1	3.0	53.5
Millet leaf sheath	0.32	74.9	47.8	4.1	1.9	64.2
Teff straw	0.51	73.5	44.2	4.2	3.3	60.0
Wheat straw	0.41	72.2	54.3	5.9	4.5	55.4
Rice straw	0.77	71.0	54.2	3.1	16.2	54.9
Rice hulls	0.66	80.0	80.8	15.6	22.9	11.3

[1] Estimated by the summative equation.
Sources: Powell (1985); Reed and Van Soest (1985).

In vitro systems

In vitro rumen systems are the most accurate methods for estimating the digestibility of feedstuffs, because they utilise micro-organisms and enzymes which are sensitive to

undetermined factors that influence rate and extent of digestion (Van Soest and Robertson, 1980; Van Soest, 1982).

Probably the most commonly used fermentation system is that developed by Tilley and Terry (1963). The method involves two stages: digestion with rumen micro-organisms for 48 hours, followed by a 48-hour digestion with pepsin in acid of about pH 2. The residue is composed of undigested plant cell wall and bacterial debris, and the results are directly comparable to in vivo apparent digestibility (Van Soest, 1982).

A modification of the Tilley and Terry system replaces the second-stage pepsin digestion with a neutral-detergent extraction which dissolves all microbial matter (Van Soest, 1982). The values obtained are estimates of true digestibility. The modification also allows estimation of cell-wall digestibility, provided that the NDF content of the sample is known. The modified procedure is as precise as the original Tilley and Terry system, has a lower analytical error and requires about half the time to complete (Van Soest and Robertson, 1985).

In vitro systems are more time consuming than chemical methods, and the digestibility values obtained are affected by problems in end-product measurement of microbial fermentation, i.e. cells, fermentation acids and gases. Moreover, access to fistulated animals to provide rumen inoculum, and close monitoring of their health, are necessary.

Cloth-bag method

Cloth bags made of nylon or Dacron and inserted into the rumen through a fistula, have been used in place of in vitro fermentation systems to estimate digestibility of feedstuffs (Kempton, 1980; Ørskov et al, 1980; Ørskov, 1988). This method gives, without using reagents, a simplified interpretation of the degradability of feedstuffs, as may be required for initial screening or ranking of a series of samples in agronomic trials.

The method requires that the bag be placed fairly accurately near the bottom of the rumen, and the porosity of the cloth as well as the ratio of sample weight to surface area of the bag need to be controlled. Cloth-bag digestibilities are subject to the same problems in end-product measurement as in vitro methods (Van Soest, 1982). The cloth used for the bags is expensive, difficult to obtain and must be replaced frequently due to wear. And, as noted for the in vitro methods, the health status of the fistulated animal must be maintained.

Another disadvantage of the cloth-bag method is the difficulty of separating the residues into indigestible feed and microbial fractions after removing the bag from the rumen. A comparison of in vitro and cloth-bag digestibilities of barley straw was made using three treatments of the residue after fermentation (Table 3). The treatments were:

- collection of the entire residue (no treatment),
- digestion of the residue with pepsin/hydrochloric acid as in the original Tilley and Terry method, and
- extraction of the residue with neutral detergent.

Table 3.*Comparison of 48-hour in vitro and cloth-bag digestibilities of barley straw, using three treatments of the residue after fermentation.*

Treatment	48-hour digestibility (%)				Significance of observed difference
	In vitro		Cloth bag		
	Mean	SD	Mean	SD	
None	49.2	5.2	52.9	10.1	NS[1]
Pepsin	56.2	5.4	56.1	8.4	NS
Neutral detergent	69.0	6.0	60.3	7.1	P<0.001
NDF digestibility[2]	58.3	6.2	46.5	7.2	P<0.001

[1] NS = not significant.
[2] Digestibility of the fibre fraction calculated by dividing the residual NDF from either the in vitro or the cloth-bag system by the amount of NDF in the sample, substracting the value from 1 and multiplying by 100.
Source of samples from seven barley varieties: B.S. Capper, ILCA, Debre Zeit, Ethiopia.

There was no difference between the in vitro and cloth-bag methods when the complete or pepsin-treated residue was used as the numerator in the calculation of digestibility. However, when the neutral-detergent residue was used, there was a large and highly significant difference ($P < 0.001$) between the two methods. This difference was caused by the greater digestibility of neutral-detergent fibre in the in vitro technique.

The difference between pepsin-treated residue and residual neutral-detergent fibre is an indication of the microbial mass present. This difference was 12.8 units for the in vitro technique and only 4.2 for the cloth-bag method, the first value being very close to the difference expected between true and apparent digestibility in vivo.

These results suggest that the microbial colonisation of bags is lower than that required for effective fibre digestion. Caution should, therefore, be used when estimating the energy value of straw by the cloth-bag technique and when comparing the nutritive value of different cereal crop residues since fibre digestion is the single most important factor in determining their nutritive value.

The results of the cloth-bag method are much less repeatable and more difficult to interpret than those of the Tilley and Terry system or the modified neutral-detergent extraction (Goering and Van Soest, 1970). Nevertheless, using cloth bags of controlled pore size (30 microns being about optimal) can be very useful in measuring in vivo rates of digestion (Van Soest, 1982).

Selecting the appropriate analytical system

Several analytical systems used to estimate the nutritive value of crop residues have been discussed. Which of these systems is selected as appropriate for use in national institutes will ultimately depend on available facilities and funding, the objectives of the research, the

accuracy required and the types of feed resources under study. All systems require well-trained technical staff.

The use of enzyme (cellulase) methods is not recommended because of their inability to estimate accurately the nutritive value of cereal crop residues. Similarly, the use of cloth-bags to estimate the digestibility of feedstuffs is cautioned against. If a national research institute has the resources to invest in maintaining fistulated animals and acquiring materials for cloth-bag trials, it could probably also obtain the necessary laboratory apparatus and reagents to carry out in vitro or chemical analyses, both of which will allow a more accurate prediction of nutritive value.

Used for cereal crop residues or a mixture of forages, the summative equation is superior to other regression systems because it allows a larger number of samples to be analysed in a shorter period of time than the in vitro systems (Van Soest, 1982). It provides comparable results to in vitro methods and also has the advantage of not needing fistulated animals. However, for a single measurement of digestibility, regardless of the type of feedstuff involved, well designed in vitro fermentation systems will provide the most reliable results.

Where researchers only infrequently have the need to estimate the digestibility of feedstuffs and do not have the financial and human resources to maintain an adequate nutrition laboratory, it would probably be more appropriate to send samples to another national agricultural research institute which has the capability to carry out the required analyses.

MAXIMISING THE USE OF CROP RESIDUES

Cereal crop residues comprise the bulk of feed available in Africa for draught animals and other livestock. If these feed resources are to be used to their maximum potential, then some knowledge of their nutritive value, coupled with improved feed management, is necessary.

Variation in digestibility

Large variations in digestibility can occur among or between different types or varieties of cereal crop residues. For example, the in vitro organic matter digestibility (IVOMD) of 26 improved varieties of sorghum grown in Ethiopia was found to range from 38.3 to 55.2% (Reed et al, 1986). Cereal crop residues (mainly barley and wheat straw) fed to working oxen in the Ethiopian highlands had IVOMD values of 45 to 60% (Goe, 1987). Several other researchers have reported large variations in IVOMD of cereal crop residues grown in Europe, the United States and Australia (Nicholson, 1984).

Rations based on cereal crop residues with moderate to high digestibility (i.e. above 50%) can provide draught animals supplemented with low levels of nonprotein nitrogen (NPN) with the energy required for maintenance and work (Soller et al, 1986). When, however, digestibility is below 50%, intake will be inadequate for maintenance and work even with NPN supplementation.

The various plant parts of cereal crop residues, but especially stovers, have different digestibilities (Hacker and Minson, 1981; Powell, 1985). When given the choice, livestock first select the most palatable fractions, i.e. leaves and the upper part of stalks (Powell, 1984). This has implications for how crop residues are conserved and fed, and what approach should be

used in carrying out nutritive analyses. If, for instance, the analyses include plant parts that are not usually eaten, the values obtained will not be representative of the actual nutritive value of feed intake.

Management of crop residues

In a major study of the use of cereal crop residues on smallholder farms in sub-Saharan Africa, McIntire et al (1989) found that grazing *in situ* is the dominant form of use throughout the continent, except in the densely populated highlands.

The nutritive quality of crop residues declines the longer they remain in the field. The most nutritive parts – leaves and the upper part of the stalk – are lost due to drying, wind damage and shattering. Turning animals onto harvested fields allows for selective grazing of plant parts, but there is also substantial wastage of the residue by trampling, in some cases between 40 and 50% (Chandler, 1984; Tessema, 1984). Even when stovers are stored and fed as whole stalk and leaves without chopping, wastage is high and intake low (Said and Wanyoike, 1987). Thus, cereal crop residues represent a feed resource with a potential that is not fully exploited on many smallholder farms.

Improved methods of storing can help maintain the initial quality of crop residues longer. But how feasible is it to introduce alternative methods? Transporting cereal crop residues to the place of storage involves additional labour, and the method of storing will change depending on the physical form of the residue. Because of their bulkiness, maize, millet and sorghum stovers are often stacked or bundled and left in the field, to be either transported to the homestead later or fed directly from the stack. In contrast, barley and wheat residues are threshed into small pieces, which makes their handling and storage easier.

The utilisation of crop residues can be improved in several ways. In the case of residues with large variations in digestibility among plant parts, increasing the amount of feed on offer to two to three times the amount consumed will allow the animal to select a better diet. The diet can be supplemented with brans and millings, oilseed cakes, legumes and fodder from multipurpose trees. Growing cereals and legumes in mixed stands will also increase the overall feed value of crop residues. A climbing forage legume which remains intact on the stover at the time of harvest can enhance the feeding value of the stover through a higher crude protein content (Dzowela, 1987). Improved tillage methods, such as surface drainage of crops grown on Vertisols, can result in higher yields of crop residues, allowing farmers to feed them to animals longer into the dry season (Jutzi, 1988). Chemical treatment of residues is not at present appropriate for the smallholder in Africa.

While certain management methods can increase both the quality and intake of crop residues, farmers' acceptance of even the simpler techniques, such as stripping of leaves, topping after maturity, chopping, and storage to preserve quality material, has been minimal because of the additional labour required and the low visibility of return (McDowell, 1988). In some instances, the management of crop residues by farmers may be adequate, but limited production of feed supplements, and the high cost of their transportation and handling, ultimately result in less efficient use of crop residues (Scarr, 1987). Genetic variation in the quality of crop residues also needs to be addressed, and this calls for greater cooperation between plant breeders and animal nutritionists.

Current use of cereal crop residues by smallholders should be examined prior to attempting to introduce alternative methods of management or allocation. Few on-farm studies have been carried out in Africa to determine the utilisation of cereal crop residues by working animals throughout the year and estimate the changes in nutritive value during storage (Mayer, 1983; Goe, 1987).

Quantitative data on the availability of crop residues on farms in relation to livestock numbers are limited (van Raay and de Leeuw, 1971; Powell, 1985). Further research is warranted to determine crop residue availability by type of crop, cropping intensity, degree of crop–livestock interaction and farmers' access to feed supplements. Simple techniques exist to estimate this parameter (Kossila, 1988).

In areas where human population pressure is bringing about land fragmentation, the management of crop residues will inevitably change. Growing competition for land between food and forage crops, but also draught, meat, milk and manure production, will ultimately dictate the extent to which alternative management practices are adopted by farmers.

For example, in some of the more densely populated highland areas of sub-Saharan Africa, where cows are kept for milk or oxen for draught, farmers are compelled to restrict grazing, and to harvest, store and selectively feed crop residues (McIntire et al, 1989). However, stall-feeding of crop residues deprives the land of manure. The division of responsibilities within the household for oxen (which are usually tended by the farmer) and other livestock (which may be the wife's responsibility) also needs to be investigated, because the best overall use of feedstuffs could, in fact, bring about conflicts in household relationships (Simpson and McDowell, 1986).

CONCLUSION

The intrinsic nutritive value of cereal crop residues can have a large effect on animal performance in response to protein and NPN supplementation. Reliable estimates of the nutritive value of cereal crop residues are necessary if these feed resources are to be used more efficiently. The analytical systems described in this paper can assist researchers to obtain such estimates and develop appropriate guidelines for feeding draught animals. The discussion of current management practices will, hopefully, prompt research on alternative methods of utilising crop residues.

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Screening stylo accessions for anthracnose tolerance: Preliminary report

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SUMMARY

THE SUSCEPTIBILITY *of stylo to anthracnose was evaluated on 17* Stylosanthes guianensis *lines acquired from the Centro Internacional de Agricultura Tropical (CIAT), Colombia, and on two reference materials, Cook and Verano stylo. Except for CIAT lines 184 and 136 and Verano stylo, all other accessions succumbed to anthracnose during the rainy season.*

Cook stylo and CIAT 11364 and 11366 did not produce any new shoots after harvest in October 1987, while two other lines, CIAT 11369 and 11374, recovered partially. When irrigated during the dry season, the remaining diseased lines recovered completely and grew without further anthracnose symptoms. CIAT lines 184 and 136 out-yielded all other lines screened, producing about 8 t DM/ha between June and October 1987.

INTRODUCTION

The genus *Stylosanthes* is one of the most important sources of pasture legumes for the tropics (Edye and Cameron, 1984). In West Africa, *Stylosanthes* features prominently in pasture work aimed at improving the nutrition of ruminants.

The pasture potential of *Stylosanthes* spp was first realised about 50 years ago, but intensive adoption around the world has occurred only during the past two decades.
Although *Stylosanthes* was introduced into Nigeria in 1940, serious efforts to evaluate its pasture potential along with other legumes did not begin until 1956, when initial evaluations took place in Ibadan, in the subhumid zone, and in Shika, in the semi-arid zone (Agishi, 1982). After screening, five *Stylosanthes* species were recommended as suitable for use: *S. gulanensis* cultivars Cook, Endeavour and Schofield, *S. hamata* cv Verano and *S. humilis* (Townsville stylo).

Stylosanthes species have a high climatic and edaphic adaptability, good feed quality and good soil conservation properties, but, as was shown by subsequent research, susceptibility to anthracnose*(Colletotrichum gloeosporioides)* can limit the adoption of most commercially available cultivars.

The International Livestock Centre for Africa (ILCA) started screening forage legumes at its subhumid zone research site in Kaduna, Nigeria, in 1979. The objective of the research was to improve the productivity of cattle owned by settled agropastoralists. Since protein deficiency in natural herbage was identified as the major constraint to animal productivity in the zone, three of

the five recommended stylo cultivars — Schofield, Cook and Verano — were initially screened in pasture trials. From 1980 onwards, they were also grown as companion crops to cereals in various combinations and sequences, and also in densely sown, fenced legume pastures – the fodder banks.

However, after a year of intercropping, the Schofield and Cook cultivars were found to be susceptible to anthracnose, and the research on animal nutrition in different production systems was continued only with Verano stylo. This research has since demonstrated various methods of producing and using Verano stylo for the benefit of large and small ruminants (Mohamed-Saleem, 1984; ILCA, 1987). It has also highlighted the need to identify more productive, anthracnose-tolerant stylo lines as alternatives to Verano stylo. Since 1981, more than 300 stylo lines have been introduced into Nigeria for screening.

In 1987, an ILCA scientist visited the Centro Internacional de Agricultura Tropical (CIAT) in Cali, Colombia, and brought back 17 *S. guianensis* lines selected for their tolerance to anthracnose. These stylo lines were evaluated on ILCA's experimental sites in subhumid Nigeria. Preliminary observations made on their performance as compared with the Cook and Verano cultivars are presented in this report.

METHODS

Seventeen *S. guianensis* lines acquired from CIAT were sown on 25 May 1987 into boxes filled with the topsoil of tropical ferric luvisol, sieved through a 2-mm screen. Fifteen of these lines (CIAT 11362 to 11376) were F_4 selections of 'common' *S. guianensis* var. *vulgaris* (J. W. Miles, CIAT, Colombia, personal communication). All the CIAT seeds planted were scarified at source with concentrated sulphuric acid and treated with Difolatan and Malathion to prevent seed-borne diseases, especially anthracnose.

Seedlings were transplanted in two separate experiment sites, one in Kaduna and the other in the Kachia Grazing Reserve. The latitude, soil types and monthly rainfall at each site during 1987 are given in Table 1. Details of the experiments are given below.

Table 1. *Description of Kaduna and Kachia experiment sites, Nigeria, 1987.*

Site and latitude	Soil type	Rainfall[1] (mm)								Total
		Mar	Apr	May	June	Jul	Aug	Sept	Oct	
Kaduna										
10° 31'N	Orthic	20	0	61	203	221	274	196	64	1 039
7° 22'E	Luvisol									
Kachia										
10° 18'N	Ferric	20	0	93	145	296	412	436	82	1 484
7° 91'E	Lusiv									

[1] There was no rainfall in the area in January, February, November or December.

Experiment 1

This experiment was conducted at ILCA's research site in Kaduna. Seedlings of *S. guianensis* were transplanted from boxes into unreplicated plots on 19 June 1987. The plots measured 1 × 1 m and were separated by 0.5-m-wide paths. A total of 150 seedlings were planted on each plot. The experiment area had never before been under stylo, but in the adjacent area, Cook stylo had been planted during the 1986 growing season and harvested in December the same year.

Two stylo cultivars — *S. hamata* cv Verano and *S. guianensis* cv Cook — were used as reference materials. On the day of seedling transplantation, 0.5 g of seed was sown in each experiment plot to simulate repeated flushes of germination which are typical of field conditions.

All plots were fertilized with single superphosphate at the rate of 250 kg/ha. The fertilizer was worked into the soil one day before transplanting. Plot borders were periodically trimmed.

On 18 September 1987, all plots were sprayed with an aqueous extract from stylo plants severely affected by anthracnose. The extract was obtained by collecting, at random, a 10-kg sample from diseased stylo plots, mixing it with clean water in a bowl and agitating the contents overnight. Before spraying, the liquid was decanted and diluted. Susceptibility to anthracnose was determined in the third week of October, using the scoring scale shown in Table 2.

Table 2. *A scoring scale to determine degree of susceptibility to anthracnose.*

Score	Leaf/stem attack (%)	Remark
1	0	Resistant
2	1–10	Moderately resistant
3	11–30	Moderately susceptible
4	31–50	Susceptible
5	51–70	Highly susceptible
6	>70	Very highly susceptible

On the day of the visual scoring, about 10 plants were cut (5 cm above ground) at random from each plot to prepare material for pathogen isolation and analysis at the Pathology Laboratory of the Institute of Agricultural Research (IAR), Zaria, Nigeria. Pure cultures were prepared as follows.

The cut plants were washed in water. Surface-sterilised using sodium hypochlorite, washed again in sterile distilled water, and then plated on potato dextrose agar streptomycin (PADS) medium. After 3 days, the organisms growing out of the plated specimens were subcultured into fresh PADS. The subcultured organisms were allowed to grow for 6 days, after which attempts were made to identify; under a light microscope, the genera of the organisms found on each stylo line.

At the end of October 1987, herbage growing on two 0.5 m^2 quadrats delineated in each plot was cut to 5 cm above ground level and dried at 60°C for 48 hours to determine dry matter

(DM). Subsamples of the dried herbage were milled and analysed for nitrogen (N) content at the Laboratory of the National Veterinary Research Institute in Vom, Plateau State, Nigeria. Herbage outside the sampled areas was then trimmed to the same height and allowed to regrow during the dry season under irrigation. Sampling of the different stylo lines for pathological investigation and DM measurement was repeated in February and April 1988, after a visual scoring of disease symptoms.

Experiment 2

Accession	Disease score[a]	October							February			April				
		Fungal type[b]:	I	II	III	IV	V	VI	VI	VII	VIII	I	II	III	VI	VIII
CIAT11362	3		x					x			x			x	x	x
CIAT11363	4		x	x	x				x		x	x		x	x	x
CIAT11364	6		x	x	x	x										
CIAT11365	4		x	x	x								x	x	x	x
CIAT11366	6		x	x	x											
CIAT11367	4		x	x	x	x		x			x					x
CIAT11368	3		x		x				x	x	x					x
CIAT11369	4		x					x		x	x				x	x
CIAT11370	4		x		x						x					x
CIAT11371	4		x	x	x			x				x				x
CIAT11372	6		x	x	x						x					x
CIAT11373	5		x		x								x		x	
CIAT11374	4		x								x					
CIAT11375	6		x		x						x					x
CIAT11376	4		x								x					x
CIAT 136	1		x								x					x

CIAT 184	1		x		x					x	x					x
Cook stylo	6		x	x	x		x	x								
Verano stylo	1		x	x				x								x

This experiment was set up at the Kachia Grazing Reserve. A 21 × 7 m plot, which had been under *Stylosanthes guianensis* cv Cook for 3 years and had had a history of persistent anthracnose attack, was trimmed to 5 cm above ground level. The plot was divided into four 21 × 1 m blocks separated by three 1-m paths. Within each block 19 strips 0.3 m wide were made by hoeing out the Cook plants.

Ten seedlings from each of the 17 CIAT lines as well as the two controls, Cook and Verano stylo, were transplanted into the strips, each line to a strip, in four replicates. The seedlings were taken from the same nursery boxes as those used in experiment 1.

Five plants within each strip were tagged and allowed to grow along with the Cook stylo regenerating outside the strips. The tagged plants were scored for disease symptoms in October 1987, using the scale given in Table 2. They were then cut and taken to the Pathology Laboratory of the Institute of Agricultural Research in Zaria for identification of pathogens. Because of lack of irrigation facilities at the Kachia site, the observations could not be continued during the dry season.

RESULTS

High incidence of anthracnose was observed 6 weeks after seedling transplantation in experiment 2. This was indicated by leaf spots with a pale centre and dark margins. The stylo lines in experiment 1 did not show such symptoms until late September 1987. i.e. after they had been sprayed with an extract from the diseased plants. The fungal associations identified in the two experiments were similar, and results for both sites are shown in Table 3.

Table 3. *Disease score and fungal types isolated from samples of screened stylo lines, Kaduna and Kachia sites, Nigeria, October 1987 and February and April 1988.*

[a] 1 = resistant: 2 = moderately resistant; 3 = moderately susceptible: 4 = susceptible; 5 = highly susceptible; 6 = very highly susceptible.
[b] I = *Colletotrichum;* II = *Helminthosporium;* III = *Phoma;* IV = *Nigrospora;* V = *Rhizopus;* VI = *Aspergillus;* VIII = *Fusarium.*

Once anthracnose symptoms developed, some lines lost all leaves and succumbed very quickly to the disease. By the end of October 1987, CIAT lines 11364 and 11366 and Cook stylo were parched and failed to produce any new shoots after harvest. A few stems survived in CIAT lines 11369 and 11374, but other lines regenerated normally. Three lines – CIAT 136 and 184 and Verano stylo – did not show any disease symptom at any time.

A variety of fungal organisms were isolated from the different stylo lines, the pattern of fungal associations being similar in both experiments. *Colletotrichum* species was predominant in the October samples of all the stylo lines evaluated, although the frequency of *Helminthosporium* and *Phoma* species was high as well (Table 3). Two other types –

Fusarium and *Aspergillus* species – were isolated from samples taken in experiment 1 during February (dry season), but there was no evidence in these samples of *Colletotrichum* species. Its reappearance in April 1988 coincides with the beginning of rains and signals a pattern of fungal associations similar to the one observed during 1987.

Stylo DM yields at first harvest in October 1987 ranged between 3.6 and 8.2 t/ha, the two top ranking lines being CIAT 184 and 136 (Table 4). Dry-matter yields at second (February 1988) and third (April 1988) harvests followed similar trends. The crude protein content (% N × 6.25) of herbage in October 1987 ranged between 14 and 20% (Table 4).

Table 4. *Dry-matter yield and herbage crude protein of 19 stylo accessions, Kaduna and Kachia sites, Nigeria, October 1987, February and April 1988.*

Accession	Dry matter (kg/ha)				Crude protein (%)
	October	February	April	Total	October
CIAT 11362	5 218	4 244	2 278	11 740	16.6
CIAT 11363	4 909	1 767	2 478	9 154	15.8
CIAT 11364	4 950	0*	0	4 950	15.8
CIAT 11365	4 058	1 533	100	5 691	17.5
CIAT 11366	6 696	0*	0	6 696	16.6
CIAT 11367	6 618	2 822	2 161	11 601	17.5
CIAT 11368	4 875	1 327	1 144	7 346	20.2
CIAT11369	5 487	155*	0	5 642	18.4
CIAT 11370	3 616	3 000	1 933	8 549	16.6
CIAT 11371	4 418	2 900	1 100	8 418	18.4
CIAT 11372	5 104	3 500	2 411	11 015	19.3
CIAT 11373	5 202	2 544	1 911	9 657	16.6
CIAT 11374	4 128	266*	0	4 394	19.5
CIAT 11375	3 880	1 200	744	5 824	15.8
CIAT 11376	5 123	2 411	2 222	9 756	16.6
CIAT 136	7 959	3 478	3 222	14 759	15.8
CIAT 184	8 153	4 244	3 000	15 397	16.6
Cook stylo	6 423	0*	0	6 423	15.8
Verano stylo	5 345	2 360	2 152	9 857	14.1

* Most or all stands died.

DISCUSSION

The agro-ecological conditions in West Africa are variably suitable for *Stylosanthes* species. Nevertheless, cultivating even a fraction of the suitable land under stylo could make a lot of difference to the national feed budget (Mohamed-Saleem et al, 1988).

Stylos can be grown in fodder banks or as companion crops with cereals. However, their susceptibility to anthracnose can become a serious hazard. Countries such as Côte d'Ivoire, Senegal and Zaire have already experienced devastation of large-scale stylo pastures on account of anthracnose (Lazier, 1984).

The presence of certain 'typical' symptoms in this evaluation, and of *Colletotrichum* species, suggests that the disease to which the screened stylo lines had succumbed was anthracnose. Free water is necessary for the development and spread of anthracnose (Irwin et al, 1984). Both Kaduna and Kachia had heavy rainfall between June and the end of September, so there was enough moisture trapped under the well developed vegetation canopy to favour anthracnose development.

The CIAT lines 136 and 184 and Verano stylo carried *Colletotrichum* organisms during the wet season but despite conducive environmental conditions, the fungus appears to have caused no reaction in these lines. Even though a latent infection is possible at plant reproduction and senescence (Irwin et al, 1984), they remained disease-free throughout the study.

The immunity of these three stylos to anthracnose appears to have contributed to their high DM yields compared with the other stylo lines screened. Because of this, they should be considered for multiplication in areas where other lines of stylo have been found useful as feed for ruminants. In some parts of Nigeria, *Cassia rotundifolia* and *Centrosema pascuorum,* which have shown promise in screening trials, could also be used to replace anthracnose-susceptible stylos.

Plant samples taken from experiment 1 in February 1988 did not contain *Colletotrichum.* Rainfall during November 1987 to April 1988, i.e the dry season, was negligible. However, test plots were irrigated, and it is possible that another factor – low diurnal temperature – inhibited the life cycle of some of the fungi, including *Colletotrichum.* At the beginning of the dry season, temperatures are highly variable, and from December to February, diurnal temperature frequently drops below 15°C, remaining low for a number of consecutive days. This is far below the temperature (20–34°C) found most suitable for the development of anthracnose (Irwin et al, 1984).

Anthracnose could have been introduced to West Africa, particularly Nigeria, through seed imported from Australia. There is no evidence in the literature suggesting any other major diseases resulting from the other fungal associations with stylo except *Phoma* species, which has been found to cause black spots in *S. guianensis* (Lenné and Calderon, 1984). As long as production of pasture seed is not well developed in West Africa, the temptation to import seed will be great. However, caution is required to prevent importing disease as well, and it may be desirable to multiply promising species in the country of use.

Stylo pastures are expected to last for many years. However, the risk of anthracnose increases with the age of the pasture. This could be controlled by chemicals, but their high cost prohibits their use over large areas of pasture. To produce anthracnose-free seed, Lenné and Sonoda (1982) have suggested strategic use of Benomyl fungicide in seed multiplication plots at the time of flowering. Also, it is desirable to cultivate a food crop every 2 or 3 years after stylo (Mohamed-Saleem and Otsyina, 1986), since the 'stylo-free' period may even help inhibit the proliferation of cropspecific pathogens in the soil.

The recovery of the anthracnose-affected CIAT lines during the dry season, when irrigated and cut at more frequent intervals, suggests that the adverse effects of anthracnose may also be mitigated by preventing an excessive vegetative canopy. Strategic grazing during the rainy season may help reduce the vegetation cover that favours anthracnose spread, but this research aspect is yet to be studied.

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Sequential cropping of Vertisols in the Ethiopian highlands using a broadbed-and-furrow system

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SUMMARY

IN A TRIAL *conducted at ILCA's research station in Debre Zeit, in the Ethiopian highlands, wheat was planted on broadbeds early in the main rainy season and chickpea at the beginning of the dry season.*

Chickpea plots were subjected to four irrigation treatments (no irrigation; irrigation at planting; irrigation at planting and 35 days after planting; and irrigation at planting, 35 days and 70 days after planting). Water was supplied through furrows until the top 10 cm of the broadbeds were saturated. Soil–water tension at 10 and 30 cm depth was measured to determine its effect on plant height, 1000-seed weight, and grain and straw yields of chickpea.

At 10 cm depth, soil–water tension differed significantly ($P<0.05$) between treatments. During the first 13 days of the trial, the 10-cm soil–water tension on control plots (without irrigation) was high enough to prevent seed germination. At 30 cm depth, the tension on control plots was significantly higher than on plots irrigated at planting, but after the second irrigation, soil–water tension was significantly higher on irrigated plots than on control plots.

Chickpea plants on plots with one irrigation were shorter and bushier than those on plots irrigated two or three times. Grain yield and 1000-seed weight from plots with one irrigation were higher than those from plots irrigated three times, but there were no differences in straw yield between treatments.

The trial showed that with a starter irrigation to aid the germination of a second crop, sequential cropping of two crops in the same growing season is feasible in the Debre Zeit area.

INTRODUCTION

Vertisols are agriculturally important soils in the Ethiopian highlands but because of waterlogging in the main rainy season, their potential for cropping is not fully realised. These soils are found mostly on land with less than 8% slope and have clay contents of 35 to 80% . Traditionally, many Vertisol crops are planted towards the end of the main rainy season and grow on residual moisture (Abate Tedla et al, 1988).

The productivity of Vertisols can be increased by surface drainage. Broadbeds and furrows (BBFs) made with low-cost, animal-drawn implements help drain excess water (Jutzi et al, 1986), thus enabling farmers to plant crops early in the main rainy season. Run-off rainwater can be conserved in ponds or reservoirs (Abiye Astatke et al, 1986) and used to irrigate the land for a second crop. Production of both human food and animal feed can thereby be increased.

The effects of improved surface drainage on the productivity of Vertisols were investigated in a wheat-and-chickpea cropping trial conducted in 1987 at ILCA's Debre Zeit research site in the Ethiopian highlands.

MATERIALS AND METHODS

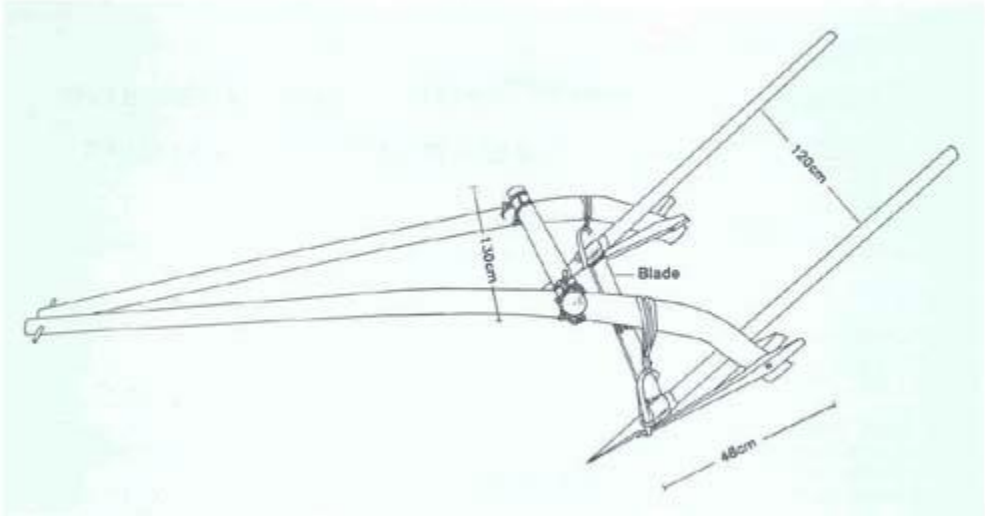
A 50 × 60 m field sloping gently (0.4% slope) along its shorter side was used for the trial. Wheat was planted on the field in uniform stands early in the rainy season, and after its harvest, the same field was cultivated under chickpea with four different irrigation treatments.

The seedbed was prepared by cultivating the field three times with the traditional plough *(maresha).* On 12 June 1987, Durum wheat *(Triticum durum* Buhae) and diammonium phosphate were broadcast on the field, at the rate of 120 kg/ha and 100 kg/ha respectively. Broadbeds and furrows were then made using an ox-drawn broadbed maker. During this operation, seed and fertilizer were covered.

The broadbeds were formed down the slope, and were 50 m long and 1.2 m wide from mid-furrow to mid-furrow. In all, 50 broadbeds were made across the 60-m wide trial field, the two on the outside serving as borders.

Wheat was harvested on 12 September 1987. Six days later, on 18 September, the topsoil of the broadbeds was disturbed to about 3 cm depth with a blade harrow attached to the broadbed maker (Figure 1), to destroy weeds. On 2 October 1987, chickpea *(Cicer arietinum,* Desi type) was planted on 48 broadbeds at the rate of 80 kg seed/ha. The blade harrow was also used to cover the seed.

Figure 1. *Blade harrow attached to the broadbed maker.*



The general climatic conditions during the chickpea irrigation trial are shown in Table 1. Total rainfall over the trial period was negligible, while evaporation was moderate and radiation ample for crop growth. The average air temperature during the trial was 20.7°C (range 6.2–30.1°C).

Table 1*. Total monthly rainfall, radiation and evaporation. Debre Zeit, Ethiopia, October 1987–January 1988.*

Month	Rainfall (mm)	Radiation (MJ)	Evaporation (mm)
October	5.0	973.7	47.3
November	0.0	972.3	59.4
December	0.4	957.6	53.4
January	4.4	714.8	58.4

Four irrigation treatments were applied, each with three replicates. The treatments were:

Treatment 1. No irrigation (control).

Treatment 2. Irrigation at planting (2 October 1987).

Treatment 3. Irrigation at planting and 35 days after planting (5 November).

Treatment 4. Irrigation at planting and 35 and 70 days after planting (10 December).

Treatments were randomised as shown in Figure 2. Each treatment plot had four broadbeds. Five furrows were used to water the four broadbeds. The furrows (0.4% average slope) were blocked at the lower end to raise the level of water sufficiently high to wet the top of the beds.

Tensiometers[1] were set at three points along the third broadbed of each plot in the first and third replications. The outer broadbeds of each plot were kept as borders to prevent spill-over effects between treatments. At each of the three points, three tensiometers were set at 10 cm depth and three at 30 cm depth. They were placed in the middle of the bed, with the outer tensiometers 10 cm from the edge of the bed.

[1] A tensiometer is an instrument which directly measures soil–water tension.

Water was applied until the top 10 cm of soil were saturated, i.e. soil–water tension was 0. On average, 30.8 m^3 of water per plot, or 1280 m^3/ha, was required to saturate the top 10 cm of soil in the first and third irrigations. During the second irrigation, saturation was achieved with only 670 m^3 water/ha.

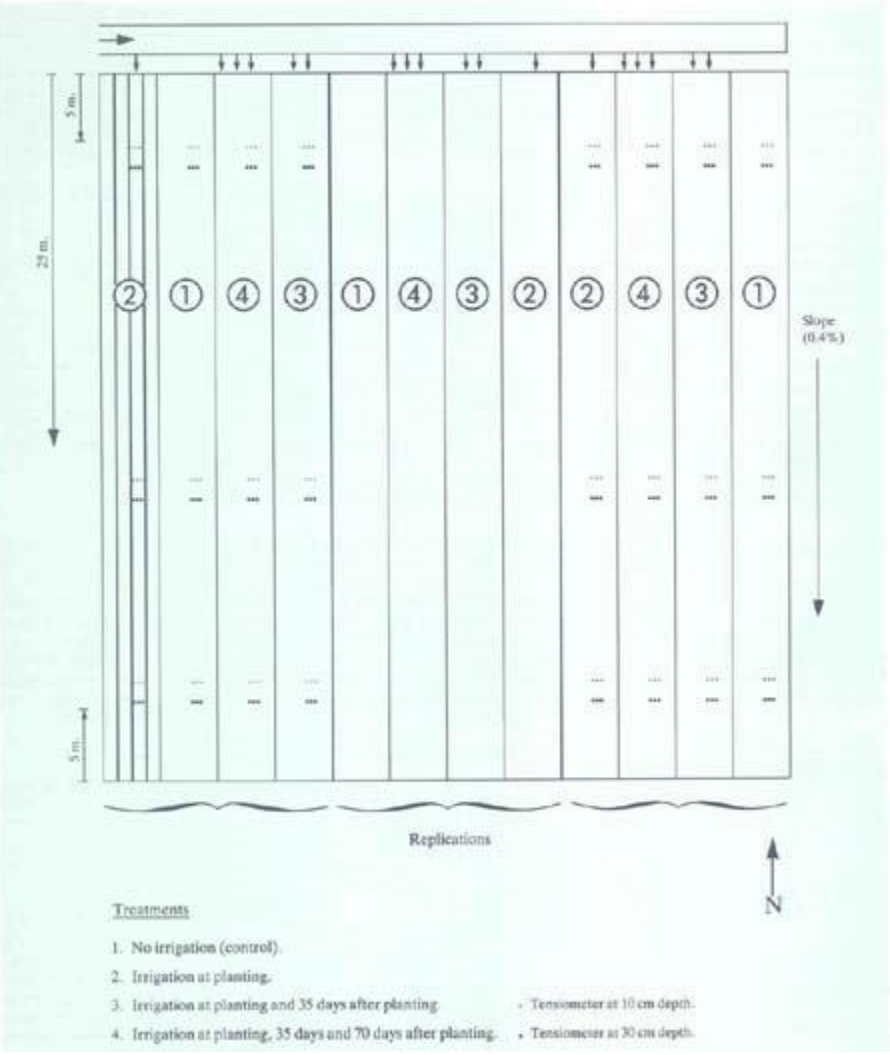
The tensiometers were read daily at 0900 hours. Readings taken during the first 8 and 13 days after irrigation at planting, during the first 5 and 10 days after each subsequent irrigation, and all readings between irrigations, were analysed. In addition, soil samples were taken weekly from 0–10, 10–25 and 25–50 cm soil layers after the start of irrigation. Four samples were taken from each layer in each treatment plot, and soil moisture content was determined gravimetrically.

Two weeks before harvesting the chickpea, six plants were selected at random in each treatment and their heights were measured. A sample area of 108 m^2 on the two central broadbeds in each plot was harvested at the end of January to determine grain and straw (DM) yields. Grain yield was adjusted to 10% moisture content and 1000-seed weights were determined.

Data were analysed using the Statistical Analysis System package (SAS Institute, 1987). The model used to analyse soil-water tension included the fixed effects of replicates and treatments,

dates and tensiometer readings, as well as all possible two-way interactions and the three-way interaction of replicates by treatments and by readings. Chickpea responses were analysed using a model where treatments and replicates were the fixed effects.

Figure 2. *Layout of a chickpea irrigation trial, Debre Zeit, Ethiopia.*



Note: Soil-moisture tension was measured in the first and third replications only.

RESULTS

Time spent on cultivation and bed reshaping

Wheat. The preparation of the seedbed for the wheat crop required three passes with the *maresha.* The first pass, made at the end of April, required 42 hours/ha to complete. The second and third passes, made at the beginning of June, took 38 and 30 hours/ ha respectively. Covering the seed and fertilizer needed two passes with the broadbed maker, which together took 11 hours/ha. Seedbed preparation and seed covering for the wheat crop thus required 121 ox-pair hours per hectare.

Chickpea. After the wheat harvest in mid-September 1987, four passes were made with a blade harrow mounted on the broadbed maker: two on 18 September, which together required 17 hours/ha, and two on 22 September. which together took 13 hours/ha to complete. Seed was covered by a single pass with the blade harrow, which required 11 hours/ha. The total time spent on bed reshaping and covering the chickpea seed was, therefore. 41 hours/ha.

Soil conditions

Soil–water tension. During the first 13 days after irrigation at planting (treatment 2), the soil–water tension of irrigated plots was significantly ($P < 0.05$) lower than that of the control plots at both 10 and 30 cm depth (Table 2). There was also a significant ($P<0.05$) difference between treatments in the 30-cm soil–water tension over the whole first-irrigation period (day 4 to 34), but no such difference was found at 10 cm depth.

Table 2. *Tensiometer readings from the first to the second irrigation for two treatments*[1], *Debre Zeit, Ethiopia, 6 October – 4 November 1987.*

Period (days[3])	Number of observations	Soil–water tension (kPa) at:					
		10 cm depth			30 cm depth		
		Mean[2]		Standard error	Mean[2]		Standard error
		T1	T2		T1	T2	
4–8	30	16.87a	9.70b	1.37	19.20a	9.57b	0.65
4–13	60	16.57a	11.00b	0.37	17.18a	10.70b	0.40
4–34	186	22.01a	20.28a	0.68	18.39a	18.39b	0.44

[1] T1 = no irrigation; T2 = irrigation at planting.
[2] For each depth. means with the same letter within a row do not differ significantly ($P>0.05$).
[3] Tensiometer readings started on the fourth day after the irrigation at planting, because during the first 3 days the soil was too wet to allow access to the tensiometers.

During the first 5 and 10 days after the second irrigation (treatment 3), plots with one irrigation had significantly ($P < 0.05$) higher 10- and 30-cm soil–water tension than the control plots and plots with two irrigations (Table 3). Over the entire second-irrigation period, control plots had significantly ($P < 0.05$) lower soil–water tension at both 10 and 30 cm depth than treatment-2 and treatment-3 plots.

During the first 5 and 10 days after the third irrigation (treatment 4), soil–water tension on control plots at both 10 and 30 cm depth was significantly ($P < 0.05$) lower than on plots irrigated once or twice (Table 4). Control plots also had significantly lower 30-cm soil–water tension than treatment-4 plots in the first 10 days after irrigation, and over the entire period from third irrigation to harvest (day 70–17). *Soil moisture content.* This was usually, but not always, lowest on control plots and increased with the number of irrigations. During the germination period (6–13 October), the top 10 cm of plots with irrigation at planting had a higher soil moisture content (35%) than control plots (26%) (Figure 3). After the germination period, the difference between the control plots and those that were irrigated at planting decreased due to the increased water use on irrigated plots by emerging seedlings. Differences in soil moisture

content between treatments occurred at second irrigation and were greatest in the top 10 cm of soil.

Table 3. *Tensiometer readings from the second to the third irrigation for three treatments[1], Debre Zeit, Ethiopia, 5 November–10 December 1987.*

Period (days)	Number of observations	Soil–water tension (kPa) at:							
		10 cm depth				30 cm depth			
		Mean[2]			Standard error	Mean[2]			Standard error
		T1	T2	T3		T1	T2	T3	
35–39	30	23.83b	30.87a	14.53c	2.34	14.50b	30.17a	12.50b	0.84
35–44	60	24.07b	33.28a	22.42b	1.53	17.30c	34.20a	22.32b	1.03
35–69	210	26.93b	45.66a	44.86a	0.89	22.13b	47.53a	47.53a	0.73

[1] T1 = no irrigation; T2 = irrigation at planting; T3 = irrigation at planting and 35 days after planting.
[2] For each depth, means with the same letter within a row do not differ significantly (P > 0.05).

Chickpea response

Chickpea did not germinate on plots without irrigation. The plants on plots irrigated only at planting were significantly (P < 0.05) shorter than those growing on plots with two or three irrigations (Table 5), but they were bushier and had a more spreading habit.

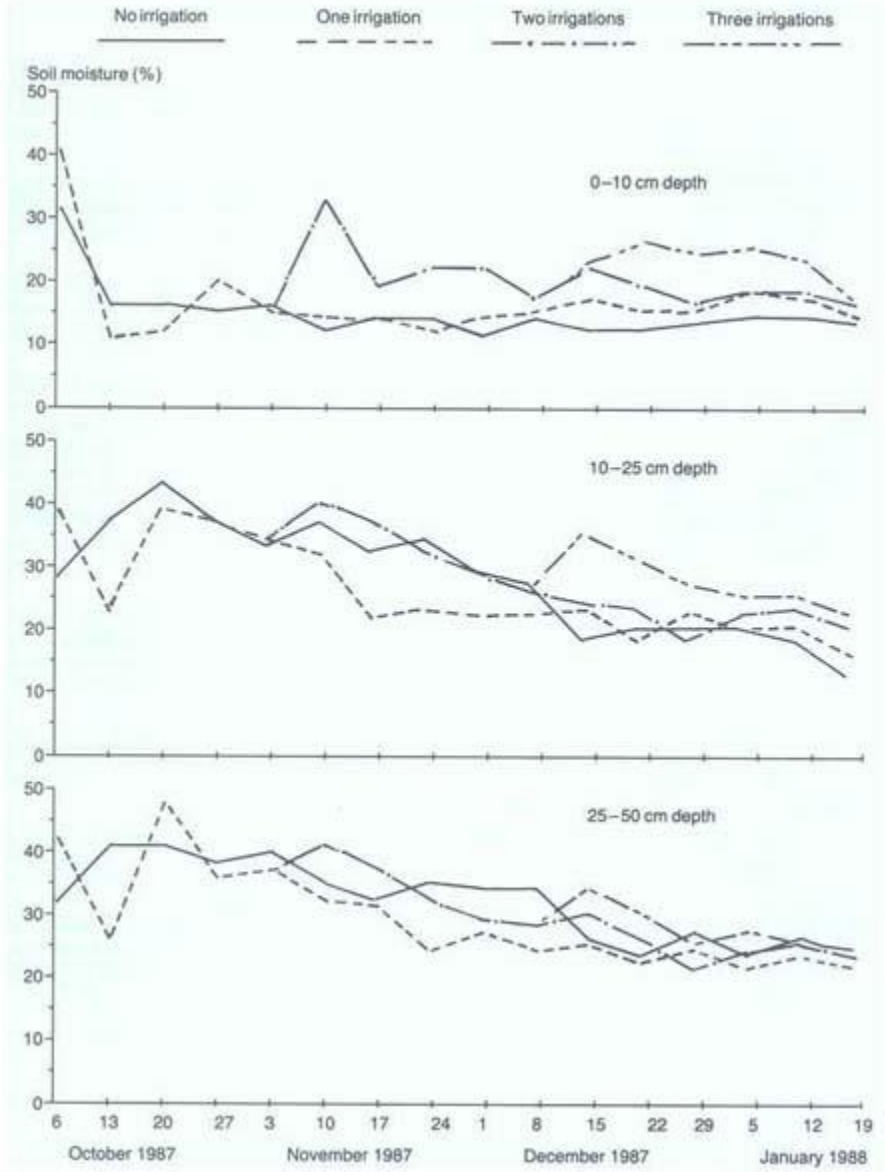
Table 5 shows that 1000-seed weight was highest from plots irrigated only at planting. The difference in 1000-seed weight was significant (P < 0.05) between treatments 2 and 4. Grain yield was significantly (P < 0.05) lower on plots with three irrigations than on plots with one and two irrigations. No difference between treatments was observed with regard to straw yield.

Table 4. *Tensiometer readings from the third irrigation to harvest for four treatments[1], Debre Zeit, Ethiopia, 10 December 1987 – 28 January 1988.*

Period (days)	Number of observations	Soil–water tension (kPa) at:								
		10 cm depth					30 cm depth				
		Mean[2]				Standard error	Mean[2]				Standard error
		T1	T2	T3	T4		T1	T2	T3	T4	
70–74	30	25.87c	44.33b	51.50a	15.83d	1.72	17.93c	50.37b	62.17a	20.50c	1.72
70–79	60	29.55c	48.20b	58.88a	27.73c	1.33	19.63d	51.37b	64.45a	30.60c	1.17
70–117	288	35.59d	58.00b	63.62a	49.59c	0.69	26.26d	62.16b	67.57a	56.40c	0.56

[1] T1 = no irrigation; T2 = irrigation at planting and 35 days after planting; T4 = irrigation at planting and 35 and 70 days after planting.
[2] For each depth, means with the same letter in a row do not differ significantly (p>0.05)

Figure 3. *Soil moisture content at 0–10, 10–25 and 25–50 cm depth for four treatments, Debre Zeit, Ethiopia, 6 October 1987–19 January 1988.*



DISCUSSION

Seedbed preparation for the rainy-season crop (wheat) required 110 hours/ha, which is similar to the time taken by farmers to cultivate wheat fields with the traditional plough *(maresha)* (Getachew Asamenew et al, 1988). Wheat seed was covered in two passes with the broadbed maker, which together took 11 hours/ha. Using the *maresha,* the same operation would have required at least 25 hours/ha (Abiye Astatke and Matthews, 1984).

Bed reshaping and seed covering for the post-season crop (chickpea) required 41 hours/ha with the blade harrow. The total time spent on land preparation and seed covering for both the wheat and chickpea crops was 162 hours/ha, which is higher than the 103 hours/ha needed to prepare

land for chickpea alone with the traditional *maresha* (Gryseels and Anderson, 1983). However, considering that two crops were obtained instead of one, the extra labour input is well justified.

Between 70 and 80% of chickpea seeds germinated following the initial irrigation at planting, whereas on non-irrigated plots no seeds germinated. The International Crops Research Institute for the Semi-Arid Tropics reported that no chickpea cultivars germinated below 20% soil moisture content (ICRISAT, 1981). In the Debre Zeit study, germination did not occur even at 26% moisture content. This suggests that while there was sufficient moisture in the soil, not enough of it was available to start germination, because soil–water tension in the top 10 cm of soil was high (16.87 kPa). Irrigation at planting brought soil–water tension sufficiently low (9.70 kPa) to release enough water for seed germination.

Table 5. *Average plant height, 1000–seed weight, and grain and straw yields of chickpea on plots subjected to three irrigation treatments[1], Debre Zeit, Ethiopia, January 1988.*

Variable	Number of observations	Mean[2]			Standard error
		T2	T3	T4	
Plant height (cm)	3	32.47a	42.10b	43.63	1.36
1000-seed weight (g)	3	111.73a	108.67ab	104.20b	1.25
Grain yield [3] (t/ha)	3	1.39a	1.38a	1.09b	0.07
Straw yield (t DM/ha)	3	2.16a	2.00a	1.92a	0.16

[1] T2 = irrigation at planting; T3 = irrigation at planting and 35 days after planting; T4 = irrigation at planting and 35 and 70 days after planting.
[2] Within rows means followed by the same letter do not differ significantly (P > 0.05).
[3] Grain yield adjusted to 10% seed moisture.

During the first irrigation period, soil–water tension at 30 cm depth was higher on the control than on irrigated plots, but in later periods, the opposite was true. This is because chickpea plants on irrigated plots started using water from the lower layers for growth.

Plots with one and two irrigations had higher chickpea grain yields than plots irrigated three times. This is different from ICRISAT's (1980) finding that the grain yield of Kabuli chickpea increases with up to four irrigations. However, the Kabuli and Desi chickpea respond differently to irrigation (Saxena, 1980). Also, the amount of plant-available water stored by Vertisols in the Ethiopian highlands is high, ranging between 324 and 686 mm (Kamara and Haque, 1988). Thus, once the chickpea crop is established with the starter irrigation, the amount of residual moisture available in the soil is sufficient to satisfy its water demand for growth.

Plots irrigated only at planting had the highest straw yield, but the difference between treatments was not significant (P>0.05). Plants growing on plots irrigated twice and three times were taller than those growing on plots with one irrigation. The second and third irrigations may thus have stimulated further vegetative growth.

CONCLUSIONS

Because of waterlogging. Vertisols in the Ethiopian highlands are left to lie fallow during most of the rainy season. Chickpea, roughpea and lentils are planted after the rains. They are heavily dependent on residual moisture, and their grain yield is low, not exceeding 1 t/ha.

The productivity of Vertisols in high rainfall areas can be increased by improved surface drainage. An example is the broadbed-and-furrow system which allows farmers to:

- Establish a first crop early in the growing season and obtain higher and more stable yields; and
- Harvest the first crop earlier and grow a second crop, using supplementary irrigation to stimulate germination.

Thus in the Debre Zeit area, where chickpea is traditionally produced and where off-season water is available, sequential cropping of cereals and legumes is not only technically viable, but also economically promising and ecologically desirable.

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Authors' style guide

POLICY AND AUDIENCE

The aims of the *ILCA Bulletin* are to present the results of livestock research by scientists at ILCA and at African national institutes, spread the knowledge of results in related disciplines, encourage national scientists to test new research techniques and technological innovations, and stimulate the adaptation to local conditions of applied research carried out by ILCA.

Thus the main audience of the *ILCA Bulletin* is made up by the following groups in sub-Saharan Africa: scientists working in livestock research and related fields, agricultural policy makers, administrators and development workers. The *ILCA Bulletin* is also distributed to scientists working outside Africa and to ILCA's donors.

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Articles may be submitted in English or French and should be from 3000 to 7000 words. The original, typed double-spaced on one side of the page only, and two photocopies, should be sent to the Director of Training and Information, ILCA, P.O.Box 5689, Addis Ababa, Ethiopia. Papers submitted will be reviewed by two internal referees whose comments will be passed on to authors. If in the referees' opinion a paper is acceptable for publication, the author should send an amended draft to the Editor of the *Bulletin* for editing and publication.

FORMAT AND STYLE

Authors should give their names and initials, titles, programme or department, institute, postal address, and telex number if available. Articles should include a summary and, whenever possible, the following sections: introduction, materials and methods, results and discussion. The findings reported should be discussed in the broader context of livestock and agricultural production in Africa.

Data in figures and tables should be clearly presented and their salient points adequately discussed in text. In the case of figures please send original artwork with the final copy, not photocopies. Sources of figures and tables should be referenced. Abbreviations and symbols used in a figure or table should be explained in footnotes below. Good-quality black-and-white photographs are acceptable for publication. A full list of references must appear at the end of the paper, and authors may also include acknowledgements, disclaimers and/or a list of less common abbreviations and acronyms.

The International System of Units (SI) should be used to specify the magnitude of physical quantities. SI units are divided into three classes: base (e.g. m, kg, s and mol), derived (e.g. m^2 and m^3), and supplementary units.

The range offered by base units can be expanded by using decimal multiples and sub-multiples described by such prefixes as kilo (10^3), mega (10^6), deci (10^{-1}), milli (10^{-3}), micro (10^{-6}) etc. The choice of the unit will depend on the number of significant figures available: when there are two or more, the numerical component should fall between 1 and 100 (e.g. the mean weight of cereal grain should be reported as 42.6 mg rather than 0.0426 g or 42600 g), but when only one

is available, it should be between 1 and 10 (e.g. yields were between 1 and 2 t/ha, not between 0.1 and 0.2 kg/m^2 or between 100 and 200 g/m^2). Applying this *scale rule* will help eliminate the frequent use of zeros or decimal points. Some SI units and symbols recommended for use in agricultural literature are given in the 'Examples' section.

Articles will be edited to maintain a uniform style; substantial editorial changes will be referred to authors for approval.

EXAMPLES

SI units and symbols

- Time: Although the second (s) is the base SI unit for time, it is rarely used in agriculture. The hour (h), day (d) and year should therefore be applied
- Area: m^2 (appropriate for studies in crop physiology), km^2 (for areas under specific crop), and ha (acceptable to quote the size of a farm or field).
- Population density: ha is the conventional reference area for plantation crops and animal stocking densities, but for plant densities m^2 is more appropriate. This descriptor conforms to the scale rule since an expression such as 10 to 20 plants/m^2 is much easier to visualise than, for instance, 100 000 to 200 000/ha.
- Mass or weight: kg, t (tonne; tolerated in compound units such as US$ 100/t product), and mg/g or g/kg (weight of dry matter produced by a crop per unit of water).
- Crop yields: kg/m^2 (fresh yields) but g/m^2 (dry matter yields); t/ha is convenient when describing agronomic response.
- Fertilizer application: kg/ha and g/m^2 for experimental plots.
- Volume: The base SI unit of m^3 is rarely convenient for agricultural measurement. Thus we will use the litre (1 dm^3) as a more relevant unit, although we will not abbreviate it because of the potential confusion with the numeral 1. Rainfall will be expressed in mm and evaporation rates in mm/day.
- Concentration: mg/kg, not 'parts per million' (ppm).
- Force: 1 N (Newton) = 1 kg m/s^2.
- Pressure: The unit commonly used by crop physiologists and soil scientists for pressure, the bar, can be converted to mega Pascals (MPa), a multiple of the SI unit, the Pascal (Pa), by multiplying by 0.1.
- Energy: J (Joule; which replaces the now obsolete erg and calorie), kJ/g (energy content of animal fodder or human food), MJ/day (animal energy consumption), and MJ/day/kg^n (in nutritional work).
- Power: 1 W (watt) = 1 J/s (for exchange of thermal energy between plants or animals and their environments).

Treatment of numbers

The numbers one to nine should be written as words, except when used as measurements or units (e.g. 1 kg, 1 month, 1 litre but one cow). All other numbers should be written as numerals: note that numbers from 1000 to 9999 should be written without a comma or space, while from 10 000 onward. a space should be included.

Common expressions and abbreviations

An increase of 6%; milk yield and consumption increased by 5% and 3% respectively; meat offtake decreased by 2 to 3%; 1300 h; 10° C; No.; 1.3 million; 1980/81 cropping season but ... Nigeria, 1980—82 (in table captions); 13 g Mo; 1 kg N; Figure, *not* Fig.; use Jan, Feb, Mar, Apr, May, June, July, Aug, Sept, Oct, Nov, Dec in tables and figures if space is not sufficient; pp. 12–19, 365 pp. (in references) but `see page 3' (in text); P = probability ($P<0.05$, $P<0.01$ and $P<0.001$); LSD = least significant difference; SE ± = standard error; d.f. = degree(s) of freedom; MS = mean square; CV = coefficient of variation.

Distinguish between 'East African Shorthorned Zebu' (specific breed) and 'zebu' cattle (humped *Bos indicus* cattle); 'Boran' cows but 'Borana' people; 'West African Dwarf goat' (breed) but 'the dwarf goats of West Africa'; N'Dama cattle etc.; sp./spp. = species (sing./pl.); cv(s) = cultivar(s); var = variety.

REFERENCES

General: Do not italicise 'et al'; write 'ed.' for 'editor' and 'eds' for 'editors'; write date of publication without brackets; do not use fullstops after authors' initials; italicise titles of published books or reports; write titles of journals, conferences and their proceedings in full; italicise titles of journals and give the volume, issue and page numbers of articles published in them.

Journal articles

Murray M and Trail J C M. 1984. Genetic resistance to animal trypanosomiasis in Africa. *Preventive Veterinary Medicine* 2:541–551.

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Wagenaar-rouwer M. 1984. Preliminary findings on the diet and nutritional status of some Tamasheq and Fulani groups in the Niger delta of central Mali. In: A G Hill (ed.), *Population, nutrition and health in the Sahel: Issues in the welfare of selected West African communities.* Kegan Paul Int., London.

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